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# Designing of 0.9 MWp Solar Power System Project for Kastamonu University

Coskun KARATAS[1] Secil KARATAY[1*] Osman CICEK[1]

[1] Kastamonu University, Department of Electrical Electronics Engineering, Kastamonu, Türkiye

**Keywords**

Solar System

PV System

Grid-Connected PV System

Power Plant

Renewable Energy

**Abstract**

Today, with increasing consumption costs, costs and needs in the field of energy are increasing exponentially. In this study, a Solar Power System project has been designed at Kastamonu University in order to meet the increasing demand for electrical energy and because it is more advantageous than other power plants, has a shorter depreciation period and a shorter installation and commissioning time. Solar Energy Systems, or Solar Power Systems are cutting-edge devices made to capture solar radiation and transform it into electrical energy that can be used. Solar Power Systems are essential for creating a greener and more sustainable energy landscape as the world community continues to emphasize sustainability. It is envisaged to use 8 inverters with 1632 panels on various roofs within the Kastamonu University campus area in order to supply the energy demand. Energy costs, power plant installation fees, depreciation process and exemptions are also cost within the scope of this study. It is concluded that approximately one third of the energy needs of Kastamonu University will be met with the proposed project.

**Cite**

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**Author ID (ORCID Number)**

| | |
|---|---|
| 0009-0004-6126-7953 | Coskun KARATAS |
| 0000-0002-1942-6728 | Secil KARATAY |
| 0000-0002-2765-4165 | Osman CICEK |

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## 1. INTRODUCTION

Electricity is a necessity for both daily living and the energy sector. Electrical energy is a crucial prerequisite in order to address the majority of human demands and to further improve technology worldwide. The production of resources required to meet necessities and the advancement of humankind are both significantly impacted by the absence of electricity. From the start of the 21st century to the present, the global and national energy landscapes have been impacted by advancements in the energy industry, rising living standards, and an exponential expansion in the global population. The energy industry has been considerably spurred by rising global temperatures, damaging ecosystems, excessive use, and changing climate patterns. According to researches, the world's energy needs are expected to increase and non-renewable energy resources will start to run out after around 2040. Natural resources are utilized to provide sustainable and ecologically friendly energy through renewable energy sources. To supply the energy demands of civilization, these resources make use of natural processes like solar, wind, water, geothermal, and bioenergy (Weiss, 1962; Park & Allaby, 2017). One of the most important of these resources is solar energy. Solar energy is a technology that uses solar radiation to create electrical energy. The solar radiation sun is converted into electricity by solar panels, making them an environmentally benign energy source. By lowering carbon emissions, this technology not only distinguishes itself as an unstoppable substitute for fossil fuels but also aids in the battle against climate change. Renewable energy sources are crucial in order to achieve the goals of sustainable development and energy security (Foster et al., 2009; Nelson, 2011).

Solar Power Systems provide a clean and sustainable substitute for conventional energy sources by using the sun's abundant and renewable energy to create electricity. Usually, these systems are made up of different

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*Corresponding Author, e-mail: skaratay@kastamonu.edu.tr

tracking and mounting methods, inverters, and solar panels. Photovoltaic cells, which make up solar panels, absorb solar radiation and transform it into Direct Current (DC) electricity. Once the DC electricity is converted to Alternating Current (AC) by the inverter, it can be used in residences, commercial buildings, and industrial settings (Dunlop, 2012; Solanki, 2013; Cicek et al., 2019). Since Solar Power Systems do not release any greenhouse gases or other pollutants during the electricity production process, this is one of their main environmental benefits. With the cost of solar technology coming down and efficiency gains driving widespread adoption, solar power is becoming a more practical and affordable way to meet the world's expanding energy needs while reducing its environmental impact. Solar Power Systems are essential for creating a greener and more sustainable energy landscape as the world community continues to emphasize sustainability (Duffie & Beckman, 2013).

In the literature, there are a lot of studies dealing with the solar photovoltaic (PV) energy systems. Thomas et al. (2007) has dealt with the technology, plans, administration, and regulations that support these fascinating advancements in solar PV electricity. In the related study, it is suggested that even though Very Large-Scale photovoltaic (VLS-PV) technology looks highly promising, a comprehensive life cycle analysis of the technology is urgently needed if it is to become truly sustainable. VLS-PV is a photovoltaic power generation system that has capacities ranging from several megawatts to gigawatts. In Zheng and Kammen (2014), a thorough dataset covering the years 2000–2012 is constructed for the PV industries in China, Japan, Germany, and the United States in order to build up a model that explains the relationships between innovation, manufacturing, and market dynamics. In the related study, it is concluded that a change in policy in the studied countries is required to fortify the industry by striking a balance between the enthusiasm and emphasis on market forces and a greater commitment to sponsoring research and development. In Ma et al. (2014), five-parameter model has been chosen for modeling PV system power generation for an island in Hong Kong. The model's simulation performance has been compared to that of other models and outside testing have been used to further validate it. This study shows that the PV simulation model created for the study is straightforward but incredibly useful for PV system engineers to precisely forecast the power generation of PV systems outdoors. In Lupangu and Bansal (2017), a variety of modeling, scaling, and maximum power point tracking (MPPT) techniques have been reviewed for grid-connected PV systems to operate efficiently. Energy regulations, different cell technologies, MPPT and converter/inverter technology, energy management and scheduling strategies, dependability, power quality, and control system concerns are among the technological obstacles that have been reviewed and discussed in the related study. In Soomar et al. (2022), the most recent developments in solar power generation equipment are examined to serve as a resource for global decision-makers involved in solar plant construction. This study suggests that the major objectives of optimization techniques are to lower emissions, operating and maintenance expenses, and investment in order to increase system reliability. In Aksoy and Ispir (2023), a PV system with a 300 kWp installed power is developed using PVsyst software in Konya province, Turkey. The system's ability to generate power has been measured and contrasted with various PV systems. The findings in this study have showed that the ratios of income values to investment costs have been 253%, 244.77%, and 126.6%. For small and medium-sized PV systems, it is concluded that mono-Si and poly-Si are quite economically feasible; however, a-Si is still not practicable because of its lower efficiency and higher prices. Benjamins et al. (2024) discusses and assesses the many potential environmental effects of introducing floating photovoltaic arrays into aquatic (freshwater and marine) environments based on the current status of floating photovoltaic technology and the known effects of related businesses. It has been suggested in this study that the utilization of Floating photovoltaic test sites will be essential to establish suitable environmental mitigation and monitoring strategies for the industry, society, and environment.

Multidisciplinary stakeholders with a range of goals and objectives are involved in the complex process of distributed solar PV design and management in buildings. These goals and objectives include achieving higher solar insolation in a specific location, producing energy efficiently, and operating and maintaining the PV system economically. Many studies that present the design and calculation of solar PV systems for buildings have been published in the literature in recent years. Similar to this study, in Sharma and Gidwani (2017), a study for solar PV system has been designed and calculated for Hostel buildings in the campus of Rajasthan Technical University (RTU), Kota, Rajasthan, India. According to this study, a 234 kW grid-connected solar photovoltaic system can provide enough electricity to offset its use, lessen reliance on the grid, and minimize energy consumption from grid supply. In another study Hamoodi et al. (2021), a solar PV system has been designed and sized for Qayyarah General Hospital south of Mosul city. When the PV*SOL program and mathematical computations have been compared, it has been observed that the solar system's components are roughly identical. Also, in a study Kavitha et al. (2021) similar to this study, a PV system has been designed with PV*SOL simulation software the results have been then utilized to determine and adjust the projected system's design. As a consequence of the simulation analysis in this study, the global irradiance of the Dual Axis Solar Tracking System is found to be 1.3 times greater than that of the other tracking systems. Some PV tools have been tested and compared in Milosavljević et al. (2022). By evaluating the most popular PV tools, this study explores which PV software is most suited for designing of PV systems. Unlike our study, it has been observed that the lowest deviation of the simulation results compared to experimental measurements has been obtained by SolarPro and PVGIS. Similar to our study, Muqeet et al. (2022) have dealt with the campus microgrids' energy management system in detail. This study also presents the research directions and related difficulties that should be taken into account in future studies on microgrid scheduling. Similar to our study, electric energy cost with using renewable energy sources in Gökceada, Turkey has been calculated in Demiroren and Yilmaz (2010). Differently, the HOMER program has been used to determine the best system design for a hybrid or non-hybrid renewable energy system in this study. It has been observed that energy costs can be lowered by selling the excess energy that is produced when the energy source is larger than the load to the grid. The findings of the simulation show that Gökceada has lower energy costs for wind energy installations. In

The Environmental Assessment Report (EIA) published by the Republic of Turkiye Ministry of Energy and Natural Resources in Turkey focuses on the environmental impacts related to the construction and operation activities of solar power plants (URL1, 2022). Solar power plants contribute to the use of solar energy instead of fossil fuels and the reduction of greenhouse gas emissions. In this project designed for Kastamonu University, it is planned to prevent 570.553 kg of carbon dioxide emissions annually. According to the EIA report (EIA, 2024), electricity production in power plants with a capacity of up to 1.000 kW based on renewable resources is exempt from the obligation to obtain a license. According to 2023 data, 679 solar power plants are actively operating, providing a total installed power of 8.335 MW. 37 of these power plants are licensed and 642 are exempt from license. Solar power plants with a project area of 2 hectares or more or an installed power of 1 MW or more (excluding roof and facade systems) are considered exempt from the EIA Regulation. The designed project in this study is exempt from the EIA regulation since the project area is larger than 2 hectares and the installed power is 0.9 MWp.

## 2. SOLAR ENERGY POTENTIAL IN TURKEY AND KASTAMONU

Turkey is located in a region called the sun belt, which is rich in solar energy. Turkey, which has a high solar energy potential due to its geographical location, has an average annual total sunshine duration of 2.640 hours (total of 7,2 hours per day) and an average total radiation intensity of 1.311 kWh/m²-year (total of 3.6 kWh per day). m²). The solar energy potential is 380 billion kWh/year (EIGM, n.d.). In 2023, 679 solar power plants are actively operating, providing a total installed power of 8.335 MW (URLx, n.d.) (EA, n.d.). In Figure 1, the Total Solar Radiation is shown for all of Turkiye.

Kastamonu located in the Western Black Sea part of the Black Sea Region has a surface area of 13.108,1 km². Total energy consumption in Kastamonu with a population of 372.633, is 778.497 MWh. With this rate, the province has a rate of 0.39% in energy consumption in Turkey. While the installed power (production) of power plants in the province is 41 MW, the installed power share in energy in Turkey is 0.06%. The only source of energy production in the province is hydroelectric power plants (Arslan, 2016). In Figure 2, total solar radiation is given for Kastamonu. Figure 3 shows global radiation values in KWh/m2-day, sunshine times in hours and PV type-area-produced energy in kWh-year for Kastamonu.

When it comes to total sun radiation, the Black Sea region, which includes Kastamonu, is one of the less promising areas. When Figure 2 is investigated, it is observed that the annual total solar radiation in no region within the borders of Kastamonu is more than 1650 kWh/m². The annual solar radiation rate throughout the province is mostly at the level of 1400-1450 kWh/m². This situation shows that the potential for solar energy production in Kastamonu is quite low on a provincial basis.

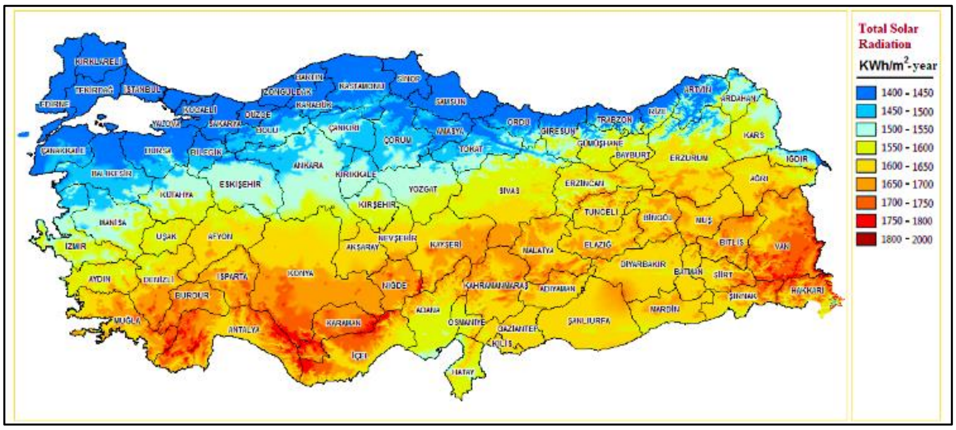


***Figure 1.*** *Solar energy potential atlas for Turkiye (Mudurlugu, n.d.)*

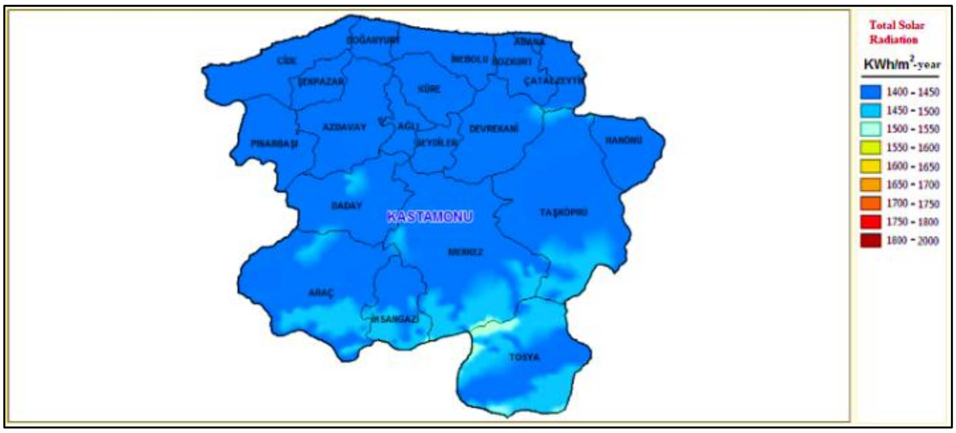


***Figure 2.*** *Solar energy potential atlas for Turkiye (Mudurlugu, n.d.)*

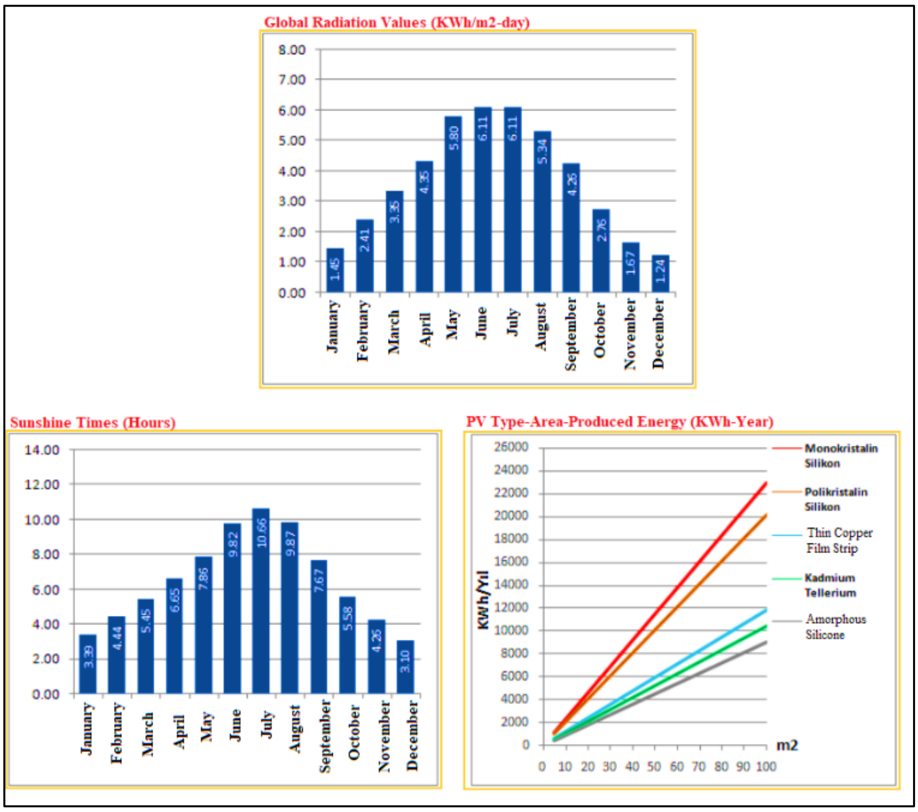


***Figure 3.*** *Global radiation values, sunshine times and PV type-area-produced energy (Mudurlugu, n.d.)*

## 3. THE DESIGN

Solar Power Systems technologies hold an important place among clean and sustainable energy sources. Universities play an important role in the development and implementation of these technologies. Solar Power Systems project design allows researchers to evaluate solar energy potential, perform system design and optimization, plan solar panel placement and work on energy storage solutions. These projects have the potential to increase society's access to sustainable energy by both contributing to academic knowledge production and enabling the development of new technologies for industrial applications. In this context, universities that focus on Solar Power Systems are of great importance for both scientific progress and social benefit. In this study, 0.9 MWp Solar Power System project is designed to meet the increasing energy needs of Kastamonu University from renewable energy sources. The roof area of the sports complex that can benefit from maximum solar radiation throughout the day is selected for this purpose. In Figure 4, the view of the project aligned to north, the west-oriented and the east-oriented panel placement of the roof are given for this roof, respectively. The panels selected within the scope of the study are PERC monocrystalline panels. Modified silicon cells with an extra layer on the back are called PERC panels. This additional layer can provide more energy by reflecting wasted light back across the n-type and p-type junctions. Furthermore, by keeping longer wavelengths from producing heat and reducing rear recombination, this reflecting surface further improves the performance of the cell. The electrical properties of the panel selected within the scope of the study are given in Table 1.

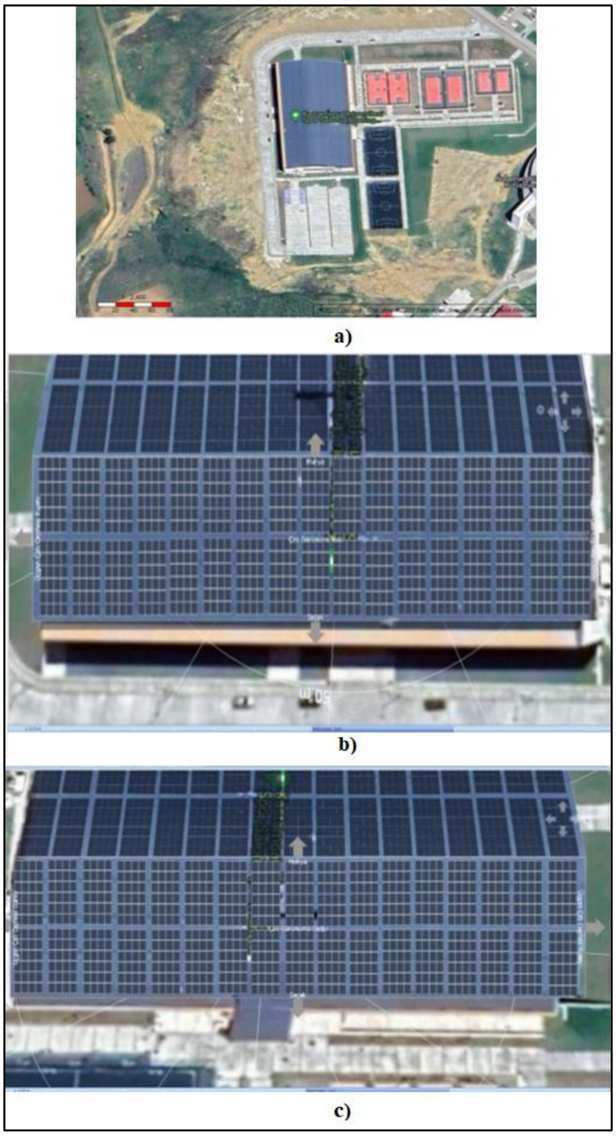


***Figure 4. a)** the view of the project aligned to north**, b)** the west-oriented panel placement of the roof,*
***c)** east-oriented panel placement of the roof*

***Table 1.*** *Electrical properties of the chosen panel*

| | |
|---|---|
| **Maximum Power ($P_{max}$)** | 545 WP |
| **Module Efficiency** | 21,29 |
| **Maximum Power Voltage ($V_{mp}$)** | 31,3 |
| **Maximum Power Current ($I_{mp}$)** | 17,42 |
| **Open Circuit Voltage ($V_{OC}$)** | 37,7 |
| **Short Circuit Current ($I_{SC}$)** | 18,45 |
| **Power Tolerance** | 0~+5 W |
| **Max System Voltage** | 1500V DC |
| **Operating Temperature Range** | -40°C~85°C |
| **Max Series Fuse Current** | 30A |

Three-Phase inverter is used in the project. Devices called three-phase inverters are used to convert three phases of direct current (DC) electricity into alternating current (AC). They are frequently employed in commercial and industrial settings where three-phase electricity is necessary. Some features such as power capacity, efficiency, protection features, monitoring and control, grid connectivity, enclosure and cooling and modularity and scalability are typical in three-phase inverters. The technical properties of the chosen inverter is given in Table 2.

***Table 2.*** *Technical properties of the chosen inverter*

| | |
|---|---|
| **Maximum Input Voltage (V)** | 1100 |
| **Minimum Input Voltage (V)** | 200 |
| **Operating Voltage Range (V)** | 550 ~ 850 |
| **Maximum Input Current (A)** | 26 |
| **Maximum Short-Circuit Current (A)** | 40 |
| **Rated Output Power (kW)** | 100 |
| **Maximum Output Current (A)** | 166,7 |
| **Maximum Efficiency (%)** | 98,6 |
| **Operating Ambient Temperature Range (°C)** | -30 ~ 60 |
| **Communication** | RS485 / USB / Wi-Fi+LAN / |

As the number and power of panels increases, the cost decreases. In Table 3, the detailed cost calculation of the project on a unit basis is given in Dollars.

***Table 3.*** *Detailed cost calculation based on piece*

| | PIECE | PRICE | TOTAL |
|---|---|---|---|
| **Inverters** | 8 | $3.957,83 | $31.662,87 |
| **PV Panels** | 1632 | $180,72 | $294.940,06 |
| **PV Cable** | | $133,98 | |
| **Transformer** | 1 | $17.978,83 | $17.978,83 |
| **Roof Mounting Apparatus** | | $5.328,21 | Note: 1,2m $7 |
| **Cable Tray*** | | | |
| **Solar Power System Panel*** | | | |
| **36KV Breaker Cell*** | | | |
| **XLPE CABLE after Transformer*** | | | |
| **Profile Foot and Spacer Holder Apparatus*** | | | |
| **Workmanship*** | | | |
| **Grand Total** | | $344.581,7662 | |

*****Above, prices of prices that may vary depending on the project are left blank.

According to the statement of the Republic of Turkiye Ministry of Energy and Natural Sources, 648 Kg of carbon emission measurement is taken as basis for 1 MWh of solar energy (URL1, 2022). The European Union Carbon Emission price is 86,77 €/Ton in 2023 and increases by 2-3 € every year. Today it corresponds to 95 dollars. It is estimated to be $100 next year. So, 1 MWh = 648 Kg 100 x 0,648 = $64,8. When the dollar exchange rate is taken as 32,09, it is 64,8 x 32,09 = 2.079,432 ₺/1 MWh. The cost and depreciation amounts calculated in the project are also given in Table 4. When calculating Table 4, the hourly production of the power plant installed power has been taken as 889,44 kWp and the current dollar exchange rate has been taken as 28,90 during the time period when the study has been carried out. With the current dollar exchange rate, the roof installation cost of the power plant is calculated as 15.422.889 ₺.

***Table 4.*** *Cost and depreciation account values*

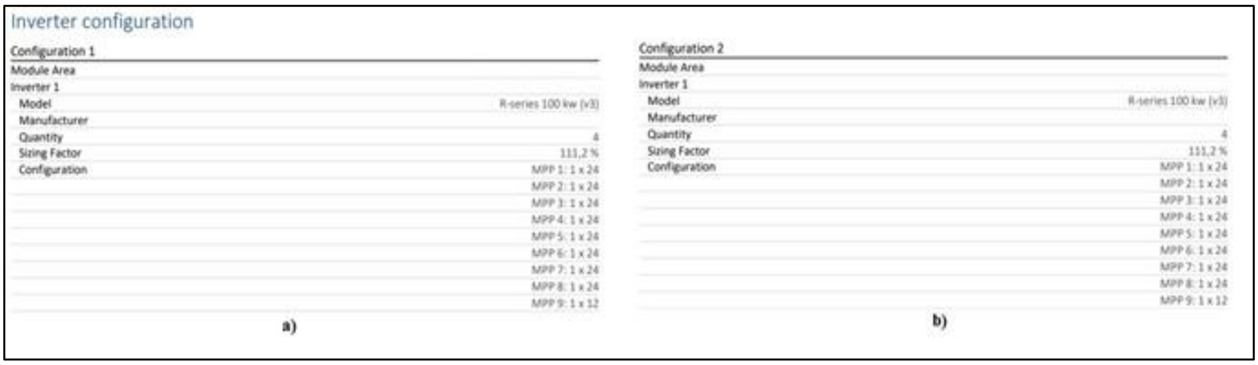
| | ANNUAL | MONTHLY | DAILY | HOURLY |
|---|---|---|---|---|
| Average electricity partial consumption of the campus (₺) | 13.365.508 | 1.113.792,41 | 36.617,8 | 1.525,7 |
| Average electricity partial consumption amount of the campus (kWh) | 3.091.695,82 | 257.641,33 | 8.470,40 | 352,93 |
| Average electricity production amount of the power plant (kWh) | 955.272,57 | 79.606,05 | 2.653,53 | 110,56 |
| Average electricity production amount of the power plant (₺) | 3.362.559,44 | 280.213,29 | 9.340,42 | 389,17 |
| Kastamonu radiation value | 1.364 kWh/m$^2$ | | | |
| Electricity sales price* | 3,52 ₺/kWh | | | |
| Power plant roof installation cost | $600 | | | |
| Loss production power of the power plant | 700,35 kWh | | | |
| Annual Electricity consumption coverage | 30,89% | | | |
| | 2024 | 2025 | 2026 | |
| Central Bank (OVP) estimated dollar exchange rate | 36,78 | 43,94 | 47,80 | |
| Earnings of the power plant (₺) | 4.672.945 | 5.582.631 | 6.073.049 | Total Earnings<br>16.328.626 |

*****Electricity Sales Price= 3,52 ₺ (January-Energy Market Regulatory Authority (EMRA))

The simulation results using the PV*SOL application are presented in the next section. PV*SOL is a software application used for PV system design and simulation that was developed by Valentin Software. Users of PV*SOL can precisely calculate and assess how solar PV systems function in a range of scenarios.

## 4. SIMULATION OF THE PROJECT WITH PV*SOL APPLICATION

PV*SOL is an all-inclusive solution for solar PV system design and analysis for engineers, installers, and consultants involved in the design and execution of solar energy projects. Users can design PV systems by defining characteristics including site, system size, orientation, tilt angle, shading objects, and PV module and inverter types. The software makes use of intricate algorithms to model the PV system's performance over time while accounting for variables including temperature, shade, solar radiation, and electrical losses. Energy yields, feed-in tariffs, self-consumption rates, payback durations, and return on investment can all be calculated by users performing financial analysis of the PV system. PV*SOL also provides PV module optimization in terms of tilt angle, orientation, and layout. It also helps choose the best components based on cost and performance standards. In this study, the designed project is simulated using the PV*SOL application (PV*SOL, n.d.). Inverter configurations 1 and 2 for the bay window roof area east and west are presented in Figure 5a and 5b, respectively. A device that changes Direct Current (DC) in an electrical circuit to Alternating Current (AC) is arranged in an inverter configuration. This configuration is frequently utilized in numerous applications, including industrial power systems, electric automobiles, and solar energy systems. A typical inverter will efficiently convert energy and adjust to the demands of AC power.



Inverter configuration

| Configuration 1 | |
|---|---|
| Module Area | |
| Inverter 1 | |
| Model | R-series 100 kw (v3) |
| Manufacturer | |
| Quantity | 4 |
| Sizing Factor | 111,2 % |
| Configuration | MPP 1: 1 x 24 |
| | MPP 2: 1 x 24 |
| | MPP 3: 1 x 24 |
| | MPP 4: 1 x 24 |
| | MPP 5: 1 x 24 |
| | MPP 6: 1 x 24 |
| | MPP 7: 1 x 24 |
| | MPP 8: 1 x 24 |
| | MPP 9: 1 x 12 |

a)

| Configuration 2 | |
|---|---|
| Module Area | |
| Inverter 1 | |
| Model | R-series 100 kw (v3) |
| Manufacturer | |
| Quantity | 4 |
| Sizing Factor | 111,2 % |
| Configuration | MPP 1: 1 x 24 |
| | MPP 2: 1 x 24 |
| | MPP 3: 1 x 24 |
| | MPP 4: 1 x 24 |
| | MPP 5: 1 x 24 |
| | MPP 6: 1 x 24 |
| | MPP 7: 1 x 24 |
| | MPP 8: 1 x 24 |
| | MPP 9: 1 x 12 |

b)

***Figure 5.*** *Inverter configurations for **a)** bay window-roof area east and **b)** bay window-roof area west*

Figure 6 shows the monthly generation forecast for the AC grid. When Figure 6 is investigated, it is observed that the generation forecast for Kastamonu is maximum in June and minimum in December. Similarly, the generation forecast for Kastamonu is highest in summer and least in winter. These forecasts are also correlated with the global radiation values and sunshine times in Figure 3. Looking at Figure 3, it is observed that both global radiation values and sunshine times are larger in June and July, as in Figure 6. Also, similarly, the global radiation values and the sunshine times have the greatest values in summer and have the smallest values in winter. It is observed that the simulation results obtained in this study are compatible with global radiation values and the sunshine times. The energy consumption of Kastamonu University campus in 2022 was approximately 3092MWh. Approximately, 1260MWH of energy can be generated annually in the simulated project that is observed in Figure 6. Thus, one third of the energy needs of Kastamonu University will be met with the designed project.

In Figure 7, global radiation, PV generator output and energy and performance ratio values are given for the bay window-roof area east and the bay window-roof area west. When the two roof areas are compared with each other, it is observed that the PV generator energy values are greater for the west bay window-roof area.

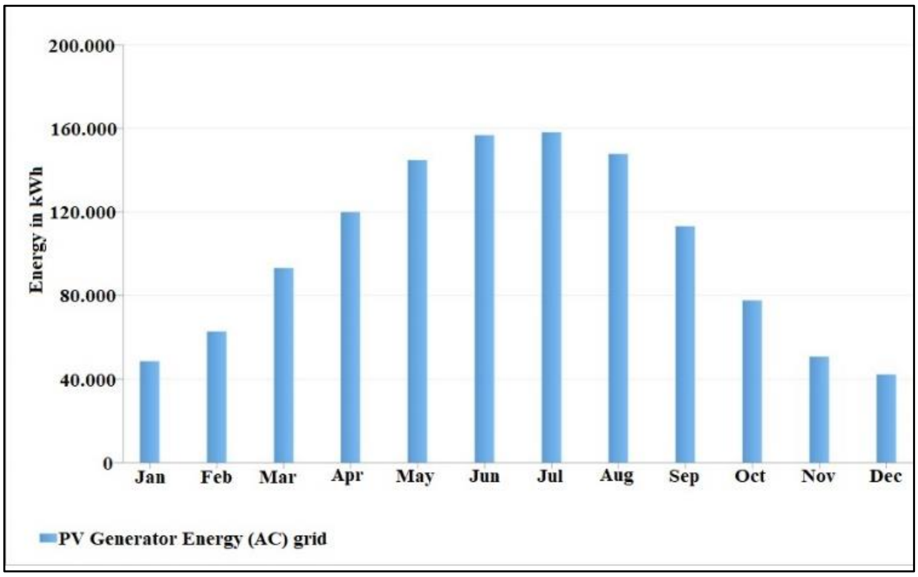
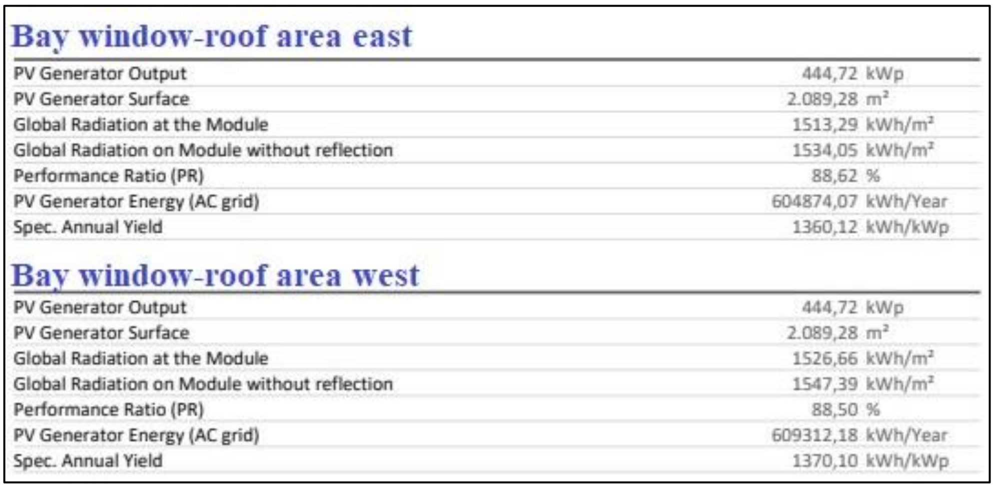


***Figure 6.*** *Monthly generation forecast for the AC grid*

In this study, PV*SOL software is used to more accurately and consistently anticipate energy generation from PV systems. Through the integration of meteorological data, geographical factors, and sophisticated modeling algorithms, PV*SOL enables precise forecasting of solar irradiance and PV system performance under a range of environmental circumstances. The study aims to evaluate the prediction accuracy taking into account the position, tilt angle, orientation of the modules, shading, and other aspects. This study also aims to provide valuable information for optimizing PV system design and operational planning through comprehensive analysis and validation with real-world data.



**Bay window-roof area east**

| | | |
|---|---|---|
| PV Generator Output | 444,72 | kWp |
| PV Generator Surface | 2.089,28 | m² |
| Global Radiation at the Module | 1513,29 | kWh/m² |
| Global Radiation on Module without reflection | 1534,05 | kWh/m² |
| Performance Ratio (PR) | 88,62 | % |
| PV Generator Energy (AC grid) | 604874,07 | kWh/Year |
| Spec. Annual Yield | 1360,12 | kWh/kWp |

**Bay window-roof area west**

| | | |
|---|---|---|
| PV Generator Output | 444,72 | kWp |
| PV Generator Surface | 2.089,28 | m² |
| Global Radiation at the Module | 1526,66 | kWh/m² |
| Global Radiation on Module without reflection | 1547,39 | kWh/m² |
| Performance Ratio (PR) | 88,50 | % |
| PV Generator Energy (AC grid) | 609312,18 | kWh/Year |
| Spec. Annual Yield | 1370,10 | kWh/kWp |

***Figure 7.*** *PV generator output, performance ratio, PV generator energy values for the bay window-roof area east and the bay window-roof area west*

## 5. CONCLUSION

In this study, a 0.9 MWp Solar Power System is designed to meet the energy demand of Kastamonu University Campus. A sports complex building with a roof area of 4.178,56 m$^2$ is chosen as the installation site. Annual production forecasts are simulated with the PV*SOL application. It has been noted that the generation forecast for Kastamonu peaks in June and troughs in December. Additionally, there is a correlation between these forecasts and Kastamonu's sunshine hours and global radiation values. It is concluded that approximately one third of the energy needs of Kastamonu University, whose annual consumption is 30,89% of the 3092 MWh consumption could be met by the designed system. It is concluded that the designed system will amortize itself in approximately three years. These results have important ramifications for encouraging the broad use of solar energy as an affordable and sustainable replacement for traditional power sources.

## AUTHOR CONTRIBUTIONS

Methodology, all authors; writing-reviewing, S.K. and O.C.; editing, S.K.; conceptualization and software, C.K. All authors have read and legally accepted the final version of the article published in the journal.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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